ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

FINAL REPORT

PROJECT NO. A-305

ON THE FEASIBILITY OF DEVELOPING AND MANUFACTURING A FAST READING CLINICAL THERMOMETER

OSMOSE WOOD PRESERVING COMPANY

MARCH 1, 1957

This document has been DECLASSIFIED.

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by

J. Elmer Rhodes, Jr.

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General Summary

The purpose of this study was to provide Osmose Wood Preserving Company with information about the feasibility of a fast reading clinical thermometer. This information was to assist them in reaching a decision whether to attempt to develop, manufacture and market such a device.

Our investigation proceeded simultaneously along three lines: (1) A check of our preliminary calculations and experimental measurements on unknown items that were required; (2) A systematic survey of scientific literature to ascertain what had been done in this field; (3) A search for patents in this field by our patent attorneys and their correspondents.

Very soon, in both the literature search and in our own calculating and experimental program, some sort of thermistor bridge began to dominate the scene. We constructed a fast (about 5 seconds required) thermistor bridge that would serve as a clinical thermometer. It required a table-type galvanometer (with a light beam for a needle) for an indicating instrument and hence did not meet our requirements of portability and cost. However, some interesting (but not surprising) facts about fast clinical thermometry were learned with it. For example: underarm temperature actually rises about one degree during the first minute or so after the armpit is closed on the thermometer probe and may rise a half degree more if kept closed for several minutes more; to get mouth temperature quickly one must probe around in the folds under the tongue to find a protected pocket -- otherwise, a minute or more may be required after the mouth closes on the probe before the temperature around the probe stops rising.

The question remaining was whether we could pass enough current through the bridge (and therefore, through the thermistor) to make the bridge output actuate a portable cheap microammeter. The answer with our fast reading probes was no. Measurements indicated that the probe would run about half to one degree centigrade above the mouth or armpit

surrounding it. This could not be compensated for in calibration as the heating would vary from time-to-time, from patient-to-patient, etc. over several tenths of a centigrade degree.

Larger thermistors could be cooled sufficiently in use but were too slow.

We were prepared to speculate cautiously on the possibilities of some compromise -- an intermediate sized thermistor, suitably mounted, which could dissipate the required power but still be small enough for fairly rapid response. Then U. S. Patent 2,753,714, which claimed to disclose just such a compromise, came to our attention. The probe configuration there described is a good one, and it was several steps beyond our progress at the time.

This patent describes just about the instrument you sought and the patent must be reckoned with. It is manufactured under the name "Swiftem" by Burlington Instrument Company, Burlington, Iowa. We have some doubt as to whether they really are able to dissipate the heat. It and our own work are described in detail in the sections that follow.

Our study finally focuses on the disclosures of U. S. Patent 2,753,714. Lest it not be clear to all readers why we pursued our three lines of investigation as will be described, we explain why in detail. At the outset three avenues were available for information on our subject. We had no way of knowing which avenue would yield the most pertinent results, so the simultaneous pursuit of all three was a course no more reckless than the pursuit of one at a time in some chosen order. Only by following all three at once could we finish in a reasonable length of time, e.g., 90-100 days. Hopefully, information obtained in one avenue would help out in others, and indeed this occurred in many instances. Without our own calculations and experiments, for example, evaluations of U. S. Patent 2,753,714 would have been less thorough and would have required much more effort.

Standards and Goals to be Met

The feasibility of developing and manufacturing a cheap fast reading, portable clinical thermometer was to be studied. Some numbers had to be attached to all these words.

The sponsor supplied us with the amount covered by the word cheap. The manufacturing cost was to be of the order of $20. This limitation narrowed our study considerably, as will be seen.

By portable, we demanded that the device be carried in the hand, and that operation of the device not require any special steady base. This (if cost did not) eliminated all delicate sensing elements such as galvanometers having torsion suspensions carrying a mirror off which a light beam reflected and served as a pointer. Such an instrument was used in our experiments, however.

By fast reading, we understood that it was desirable to obtain a reading in about 3 seconds after applying the temperature sensing probe. We were aware, however, that any reading time up to about 10 seconds was in some degree acceptable. Our fastest laboratory model responded in about 5 seconds, while 7 seconds is claimed for the supposedly practical instrument disclosed in U. S. Patent 2,753,714.

For accuracy demanded in a clinical thermometer we arbitrarily set ourselves the standard of $\pm$ 0.1°F (5/90 = 1/18°C) over the range 94° to 108°F. This was in line with our experience with mercury-in-glass clinical thermometers. Our literature search, however, revealed Federal Specifications GG-T-311a (Reference 21) for acceptance of clinical thermometers furnished to the Government. These specifications were more lax. They required a range 96° to 106°F (35.5° to 41.0°C); accuracy and repeatability of readings of $\pm$ 0.2°F (1.1 C$^\circ$) at 98°F and 102°F (or 37°C and 39°C) and $\pm$ 0.3 F$^\circ$ ($\pm$ 0.17 C$^\circ$) at 106°F (41°C).

Throughout the rest of our work the Federal Specifications were regarded as a minimum acceptable standard of accuracy, while we continued to aim at our own.

General simplicity in operation was considered necessary and was an end kept constantly in mind.

Our Program of Calculations and Experiments

Thermocouples: Our original conclusion on thermocouples was not altered when our considerations were examined more closely. A reference temperature sink must be available that is known as accurately as one wants the measured temperature. Presumably, this is a difficulty with thermocouple instruments now on the market for measuring skin temperature, according to Reference 9 of our literature study. Such an instrument is the "Dermolor", McKesson Appliance Company, 2228 Ashland Street, Toledo, Ohio, and another is manufactured by U. M. A., Inc., 56 Cooper Square, New York 3, New York.

Even granting that the reference junction temperature problem could be met, a cheap meter would not be sensitive enough for clinical use. A 10-junction thermopile is about as many junctions as could be effectively put into a probe, and this -- using typical metals -- would give an emf of 4×10^{-4} volts per C°. If the meter range were to cover 6 C°, then the meter would need to deflect full scale when the circuit emf was 2.4×10^{-3} volts.

A meter we consider typical for such use would have internal resistance of 20 ohms and if the circuit external to the meter were 20 ohms the current for full-scale meter deflection would be 2.4×10^{-3} volts/40 ohms = $.06 \times 10^{-3}$ amperes.

One of the most sensitive portable meters in this class requires 0.5×10^{-3} amperes for full scale deflections.

Thus, the available sensitivity is only a tenth what we need. Design with a hundred junctions, while not impossible, would be troublesome if resistance external to the meter were to be kept below 20 ohms. Its construction would have to be considered along with the reference temperature problem for which we have no really satisfactory solution.

An amplifying device would raise the manufacturing cost too much. (See below.)

Thermocouple devices were set aside in favor of thermistor devices.

Amplifier: One of our electrical engineers was consulted on the general problem of an amplifying device for either a thermocouple device or for a resistance thermometer bridge.

He concluded that a magnetic amplifier developed for just this application was the best answer. A magnetic amplifier itself is fairly cheap. Material costs would run $10 to $25, depending on the design. However, they need a source of power of audio or low radio frequency. The neatest source would be a power transistor oscillator, but such a power supply would cost $20 to $50 for materials -- largely because of the cost of power transistors. (This is the cost in quantity to a manufacturer.)

Thus, a usable magnetic amplifier and power source would cost $30 to $75 for materials at manufacturers prices. Other manufacturing costs would have to be added to these.

A vacuum tube oscillator for a power supply would be a little cheaper, but it would require high voltage B batteries.

Our general conclusion was that special light weight portable amplifiers could probably be developed that would be satisfactory on both resistance thermometer bridges or for thermocouples, but their cost removed them from present consideration.

Resistance Bridges:

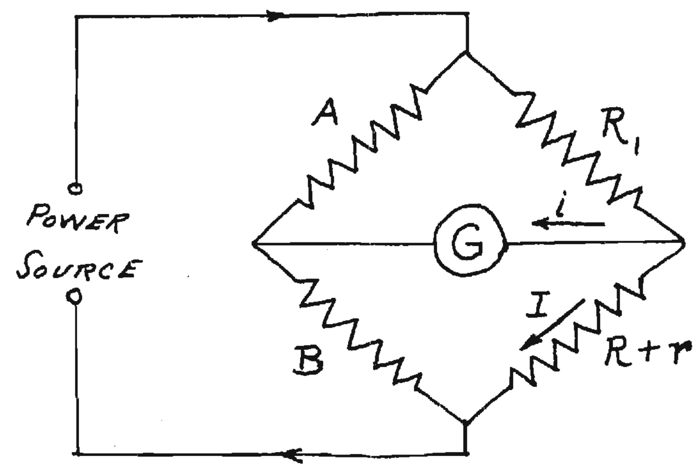

Figure 1

A resistance thermometer is usually arranged in a "bridge circuit" like that sketched in Figure 1. The resistance (R + r) is temperature sensitive. The bridge is balanced when $A/B = R_1/(R + r)$. We will consider bridges very near to the balance condition, and we will specify $A/B = R_1/R$ and then r measures the unbalance. The fractional unbalance is r/R, and this quantity will be proportional to the temperature departure from the temperature at balance.

At balance the current i through the current sensing instrument G is zero. The current through G will be proportional to r for small degrees of unbalance, and this is the situation we will consider.

Matching the Bridge and the Meter: Given a set of proportions (ratios between resistances of the 4 bridge arms) for a bridge, and given a meter, there are general theorems that tell us that we will obtain the greatest meter deflection for a given fractional unbalance if the meter impedance z matches the impedance it "sees" looking into its terminals of the bridge.

All our calculations will be based on such an impedance match and all our experiments were with this condition nearly met.

Bridge Sensitivity: Our experiments and calculations are further limited to equal-arm bridges (nearly so in the experiments). Such bridges have $A = B = R_1 = R$ and the matching meter impedance is $z = R$. These bridges are attractive for several reasons. First, their sensitivity for a given current through R is not affected by the impedance of the power source. The current through indicator G is

$$i = \frac{I}{4}\,\frac{r}{R} \tag{1}$$

where I is the current through R. If the power source is a low impedance one (battery with low internal resistance, for example) the equal-arm arrangement is the most sensitive bridge for any given value of I. If the power source is a high impedance source (constant current source) then the equal-arm arrangement has the same sensitivity, and calculations show that the theoretical limit of sensitivity is just twice this amount. This limit is attained with an utterly impractical bridge that is wasteful of power. Very high currents must flow through arms A and B to appreciably increase the sensitivity over that of an equal-arm bridge with the same I.

The equal-arm bridge is practically about as sensitive a bridge as can be built, and is within a factor of 2 of the limiting sensitivity. Thus, any results for such a bridge can be immediately evaluated in practical terms. Actually we can effectively double the sensitivity of an equal-arm bridge by using two temperature sensitive arms, that is, by replacing A by another identical temperature sensitive member like (R + r).

Power Dissipation: A constant concern in all resistance thermometry is how much the electric power delivered to the resistance thermometer element by the measuring current raises the temperature of the thermometer above the surroundings whose temperature is supposedly being measured.

In very accurate laboratory thermometry the usual practice is to measure the resistance of the thermometer with several different measuring currents and extrapolate to the resistance that presumably would be measured with zero current. In our application this is too troublesome and time consuming, so we must try to get an arrangement in which this temperature rise is negligible, or at least where its change from one measurement to another is negligible so it can be accounted for in calibration.

For our equal-arm bridge the power dissipation in the thermometer arm is closely related to the power dissipation in the indicating meter at full scale. (This quantity is often an appropriate index of quality in a current sensing meter.)

Once the temperature range of our instrument (35.5°C to 41°C, a range of 5.5 C°) is fixed, and the type of resistor for the thermometer chosen, the value of r/R for full-scale meter deflection can be found.

For thermistors, for example, the fractional change of resistance per centigrade degree lies between 0.03 and 0.04, while for unalloyed metals it is about one-tenth this amount. Alloys show even smaller temperature coefficients of resistance. For thermistors r/R for full-scale deflection would be between $5.5\ C^{o} \times .03\ \text{deg}^{-1} = 0.165$ and $5.5\ C^{o} \times .04\ \text{deg}^{-1} = 0.220$.

For any thermometer element call this value of r/R for full-scale deflection $(r/R)_1$.

Straightforward calculations, using the bridge sensitivity of equation 1 show that

$$(2) \qquad \left\{ \begin{matrix} \text{Electric Power} \\ \text{dissipated in R} \end{matrix} \right\} = \frac{16}{(r/R)_1^2} \left\{ \begin{matrix} \text{Power dissipated in meter} \\ \text{at full-scale deflection.} \end{matrix} \right\}$$

if the current through R is to be large enough to give the desired sensitivity.

A survey of cheap meters (retail cost under $16) indicated that the power dissipated in the meter at full-scale deflection would be between about 1 and 20 microwatts. About 5 microwatts represents what we considered as the best we could do reliably. The more sensitive meters are rather delicate for portability but not out of the question.

If $(r/R)_1$ is taken, typically, as 0.2 for a thermistor thermometer probe, then the coefficient $16/(r/R)_1^2 = 400$.

About 2000 microwatts (and at least 400 microwatts) would have to be dissipated in the thermistor to attain the desired sensitivity.

The specifications in Columns 3 and 4 of U. S. Patent 2,753,714 indicate that they are dissipating about 3,000 microwatts in their thermistor. They use mercury cells, each with emf about 1-1/3 volts, as a power source. They do not specify how many cells but their circuit drawings indicate 3. This places 4 volts across the bridge. A thermistor with their specifications (2000 ohms at 25°C) would show about 1250 ohms at 37°C. They probably use, essentially, an equal-arm bridge though they do not say so. This would place 2 volts across the 1250 ohms of the thermistor which corresponds to an electric power dissipation of 3200 microwatts.

Experiments with Thermistor Thermometers: Our first object was to obtain a really fast responding thermometer. Considerations of ruggedness, sterilizability, etc. were set aside until we could demonstrate what was necessary to obtain the desired speed of response.

This required that we reduce the ratio of heat capacity of the probe to the effective thermal conductivity between the thermometer element and the object whose temperature was to be measured. We obtained some very small thermistors (Type 32CH1 obtained from Gulton Industries, Inc., 212 Dunham Avenue, Metuchen, New Jersey). These consist of small beads a few thousandths of an inch across with very fine (.002" or less) wire leads.

These were mounted in several ways to effect protection and at the same time rapidly conduct heat between the thermistor and surroundings.

Several arrangements were either unsuccessful or marginal from the standpoint of time of response and will not be described in detail.

A successful arrangement sandwiched one of these bead thermistors between two 3/4" squares of .0005" aluminum foil with glyptal for cement and insulation.

This arrangement had a time of response (time required to obtain a satisfactory reading) to underarm temperature of about 5 seconds.

The bridge and thermistor were calibrated in a water bath against a laboratory standard thermometer with a small bridge current (34 microamps). Then the temperature of the thermistor placed underarm was measured by the bridge circuit as the bridge current, and hence the current through the thermistor was systematically varied. As the power delivered to the thermistor increased so did its temperature. The dissipation constant was about 600 microwatts per centigrade degree.

Another fast responding thermistor was the Western Electric type 14b, a bead type embedded in the end of a glass probe about 3 inches long. The response time for this one was also about 5 seconds. It has a greater ability to dissipate heat.

Dissipation "constants" underarm ran between 3,000 and 4,000 microwatts per centigrade degree. Variation from one placement to another is to be expected in all of these.

Dissipation constants with the probe under the tongue ran between 2,000 and 5,000 microwatts per centigrade degree.

From this we see that the variation in ability to dissipate heat varies over a two- or three-to-one range for different placements and the temperature rise necessary to effect the required dissipation, 2,000 microwatts, is between half and one centigrade degree. Thus calibration would be reliable only to about half a centigrade degree and this is unsatisfactory for a clinical thermometer.

Dissipation measurements were made on a Western Electric type 16A thermistor. This is a round disc 0.4 inches in diameter and 0.2 inches thick. This thermistor showed an underarm dissipation coefficient of between 20,000 and 40,000 microwatts per centigrade degree. The temperature rise was too small for a very accurate measurement.

This was a barely sufficient rate of dissipation, but the time of response was much too slow, over a minute.

Our next step was to speculate on the possibility of a configuration consisting of a thermistor of size in between the very small beads, and the rather large disc that would effect a compromise between time of response and ability to dissipate the required amount of heat. Then U. S. Patent 2,753,714 turned up, and it claimed to disclose just such a compromise. At this point we closed our experimental work.

Nickel Wire Thermometers: Early in our experiments several nickel wire thermometers were planned or constructed. However, before they were put to use it became evident (see section on power dissipation, equation 2) that they would have to dissipate about 100 times the power of a thermistor thermometer with the same sensitivity. This is because the temperature coefficient is about 0.1 that of a thermistor and hence the required $(r/R)_1^2$ of equation 2 would be only 0.01 that of a thermistor. It appeared that we could arrange a thermistor in almost any form that we could arrange a wire wound thermometer. Hence, with power dissipation a major problem with thermistors, we dropped consideration of nickel wire thermometers.

Costs: The meters under consideration retail for $16 or less and thermistors for $2 to $4 each. The precision resistors we used for the other arms of the bridge retail for about $1 each. This put the retail price of components right near the $20 manufacturing cost you had given us. This did not include a case and other miscellaneous items, but we felt that the differences between retail and manufacturer's prices would allow enough margin to allow the required manufacturing price to be met.

Literature and Patent Search

An extensive search was made of the literature of the past ten years and forty or fifty references were investigated. The more applicable ones are included in the references at the end of this section and their numbers are referred to in the paragraphs to follow.

Thermocouple Instruments: Thermocouples are used for special medical applications (1, 2, 3, 4) like measurement of skin temperature (1) and blood temperature (3, 4). However, even in relatively bulky portable instruments (2), eg., 10" x 11-1/2" x 8" case, 12 lbs., "room temperature" is used as the reference junction and hence requires continuous adjustment. Such an instrument is troublesome to use (9).

These instruments do not overcome the difficulties raised in our calculations section. The reference junction problem has no satisfactory solution and the sensing meter is a delicate light beam type.

Manufacturers of medical thermocouple type devices are U. M. A., Inc., 56 Cooper Square, New York 3, New York and McKesson Appliance Company (Dermolor), 2228 Ashland Street, Toledo, Ohio.

Resistance Thermometer Instruments: Likewise, resistance thermometers have had limited medical use. At least one metallic resistance thermometer (5) has been built for clinical use. It requires a built-in light beam galvanometer, however.

Thermistors hold the field, however, in the years since World War II. These were often for special purposes like blood temperature (7, 18), skin temperature (9, 13) and internal temperatures (10). Bead thermistors mounted in hypodermic needles are available commercially (18) for about $100 each (VECO price list).

For blood temperature the heat dissipation problem is much less pressing than in a general purpose instrument which must measure say, underarm temperatures. This may account for the lack of mention of this problem in some of these articles. However, some general purpose instruments have been described in which the problem seemed to be unrecognized.

Among these are hand made portable instruments somewhat like we have considered. One was for measuring body temperature of baby pigs (12), another for skin temperature (9) and another was a general purpose thermometer for research on mice (15).

A general clinical thermometer using thermistors employed by Paris hospitals was described in some detail (16), but no mention was made of heat dissipation.

Reliability of thermistors over long periods of time is attested by manufacturers (18) and by independent investigators (14, 17).

For internal body temperatures E. M. Rauh and Company, Inc., 2 Parker Avenue, Buffalo 14, New York, manufacturers a resistance thermometer bridge for $250. It incorporates a reflecting galvanometer and will not meet our requirements of simplicity of operation.

Texas Instrument Company manufactures a resistance thermometer for clinical use costing $82. Size is 5" x 3" x 1-1/2". It has interchangeable stainless steel probes, 4" x 3/16", that cost $6.90 per dozen. We have no information on time of response, but presumably it is fairly long as it is designed so that probes can be passed out to a number of patients, presumably to await equilibrium, and subsequently the instrument is connected for measurement.

An instrument whose description reads like our specifications was described in a well written article (11) by the inventors -- Col. G. T. Perkins, Director of the Dental Division of the Army Medical Service Graduate School, Washington, D. C., and J. E. Colby of Battle Creek, Michigan. They outline the history of clinical thermometry over the past 90 years and then describe their instrument. It registers in 5-7 seconds at the touch of a finger-button switch on the plastic case about the size of a photographer's light meter, etc. Usefulness mentioned saving of time for physician, especially with small children, etc.

The same instrument is less ably described in two other articles (19, 20). One (19) says, "It is being presented to medical and allied professions by the Medical Research and Development Board, U. S. Army." The other (20) mentions that it is being manufactured by Burlington Instrument Company, Burlington, Iowa.

These articles did not describe the necessary details of the probe, but the same instrument is revealed in U. S. Patent 2,753,714 and there probe details are disclosed. The silver tip (see patent) is well designed to bring the associated thermistor to equilibrium rapidly and to dissipate heat effectively. It may meet the specifications it claims. It was apparently developed under government auspices and a good deal of thought and experimentation probably went into the probe tip development.

Our own considerations lead us to believe that this instrument, too, suffers from too much temperature rise of the thermistor.

References:

1. "Study of Thermocouples as Skin Thermometers," A. M. Stoll, J. D. Hardy; J. Appl. Physiology 2, 531-43 (1950).

2. "U. M. A. Thermocouple Accepted," J. Am. Med. Assoc. 143, 971 (1950).

3. "Needle Thermocouples," H. M. Whyte, S. R. Reader; J. Appl. Physiology 4, 623-7 (1952).

4. "Improved Needle Thermocouple for Subcutaneous and Intramuscular Temperature Measurements in Animals and Man," J. Krog; Rev. Sci. Instruments 25, 799-800 (1954).

5. "Portable Precision Resistance Thermometer Equipment for Mains Operasion," J. A. Hall; J. Sci. Instrument 26, 392-6 (1949).

6. "Properties and Uses of Thermistors -- Thermally Sensitive Resistors," J. A. Becker, C. B. Green, G. L. Pearson; Electrical Engineering 65 (Transactions Section) 711-25 (1946).

7. "A Simple Resistance Thermometer for Blood-Temperature Measurements," L. F. Drummeter, W. G. Fastie; Science 105, 72-5 (1947).

8. "Thermistors as Components Open Product Design Horizons," K. P. Dowell; Electrical Manufacturing 42, 84 (August 1948).

9. "Skin Temperatures in Peripheral Vascular Disease -- A Description of the Thermistor Thermometer," Winsor Travis, M.D.; J. Am. Med. Assoc. 154, 1404-7 (1954).

10. "Sterilizable Thermometer for Measuring Intra-abdominal Temperature," J. Grieve; Lancet 2, 431-2 (1951).

11. "A New Horizon for Clinical Thermometry," G. T. Perkins, J. E. Colby; Hospitals 28, 89 (December 1954).

12. "Thermistor Temperature Bridge," J. G. Taylor, M. T. Orem; Agricultural Eng. 34, 256, 258 (1953).

13. "Application of Thermistor to Measurement of Subcutaneous Temperature During Hypothermal Injury in the Rat," R. S. Gray, A. E. Axelrod; Proc. Soc. Exp. Biol. 83, 269-72 (1953).

14. "Use of Thermistors in Precise Measurement of Small Temperature Differences," R. H. Mueller, J. J. Stolten; Analytical Chem. 25, 1103-6 (1953).

15. "Thermistor Electronic Thermometer," R. W. Woods; Science 121, 337-8 (1955).

16. "Thermistor Thermometer," Alfred Haas; Radio Electronics 26, 47 (July 1955).

17. "Thermistor Thermometer," J. R. Squires; Radio Electronics 27, 75 (April 1956).

18. Thermistors (VECO Data Book), Victory Engineering Corporation, Springfield Road, Union, New Jersey, 1955.

19. "Electronic Thermometer is Developed by Army Dentist," Electrical Engineering 74, 62 (1955).

20. "Electronic Thermometer for Clinical Use," Tele-Tech and Electronic Industries 13, 32 (August 1954).

21. Thermometers, Self-Indicating, Mercury in Glass (Fever), Fed. Specs. GG-T-311a.

Patents: Our patent attorneys were ordered to make a "State of the Art Search, Fast Reading Clinical Thermometers." They turned up 44 U. S. patents, and we have been through the 41 that have arrived so far. Only the Perkins patent is really applicable to our development, and it pretty well anticipates what we wanted to develop. A list of these patents follows:

Callendar	598,905	Dallman et al	2,050,878
Haagn	880,074	Bergeron	2,297,868
Brueckner	1,328,824	Obermaier	2,321,846
Evins	1,552,284	Smith	2,359,334
Evins	1,610,271	Kliever	2,357,745
Harrison et al	1,573,606	Wise	2,450,263
Hayman	1,648,899	Redding	2,546,275
Evins	1,648,939	Redding	2,546,276
Hayman	1,648,942	Wapner	2,570,414
Bliss	1,190,978	Grez	2,637,316
Porter	1,363,267	Basham	2,635,137
Foote	1,593,623	Hass	2,542,671
Edwards et al	1,951,276	MacCallum et al	2,552,196
Mears	2,161,370	Relis	2,595,297
Bloomheart	2,195,019	Andresen	2,618,976
Crawley	2,669,986	Schroeder	2,657,580
Weisheit	2,711,650	DeWitte	2,737,810
Gilmont	2,679,759	Perkins et al	2,753,714
Cross	2,722,641	Whaley	2,763,935
Dickey	2,728,833	Schweig et al	2,777,326
		Picciano	2,379,317

Patents cited by attorney but not yet delivered to us:

Haagn	845,413
	2,102,030
	2,612,780

Conclusions

At the present state of the art thermocouples and metallic resistance thermometers cannot be adapted into clinical thermometers that are as cheap and convenient to use as we want.

Thermistors may be so applied as resistance thermometers but the problem of heat dissipation must be balanced against time of response in a well designed probe.

Just such a design is claimed by Perkins and Colby in journal articles and in their patent. They are aware of the heat dissipation problem, but they make no statement on how much dissipation affects their calibration. This instrument is apparently on the market (we do not have the price) and must be reckoned with as competition. Also their patent must be reckoned with. There is a possibility of royalty free license though because of its development by the government.

This may be enough for your decision of whether to go forward with developing such an instrument. However, to round out our conclusion we will state our position on further development. The Perkins and Colby design is several steps ahead of our own development at the time it came to our attention. If we were commissioned to develop a "better" thermistor probe our first step would be to make or obtain a probe such as they specify. We would perform measurements on it and then go on from there.

It is possible that their probe is satisfactory so that no further development is indicated. We doubt this, however. Should it not be satisfactory we would start from their design. We would expect substantial improvements to be difficult and costly if attainable at all. We could ascertain whether the Perkins instrument meets our requirements or not for the cost of the instrument plus about $300. We offer no estimate on the cost of developing a satisfactory probe if the Perkins probe is unsatisfactory because we feel our chance for success would be very small.